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(54) Mercury-free metal halide lamp and a vehicle lighting apparatus using the lamp

(57) A metal halide lamp comprises a light-transmitting discharge vessel having a discharge space portion, a sealed portion, and a pair of electrodes projecting into the discharge space. The discharge vessel is constructed and arranged to have a D/L ratio being in a range of about 0.25 to about 1.5 and a t/L ratio being in a range of about 0.16 to about 1.1, wherein L is an interspace of tips of the electrodes, D is a maximum inner diameter of the discharge vessel, and t is a maximum wall thickness of the discharge space portion. An ionizable filling contains a rare gas and a metal halide including at least sodium (Na) or scandium (Sc) and does not substantially include mercury (Hg). Each of conductive wires is connected electrically to the electrodes extending from the discharge vessel. The metal halide lamp may be used for a metal halide lamp apparatus or a vehicle lighting apparatus.

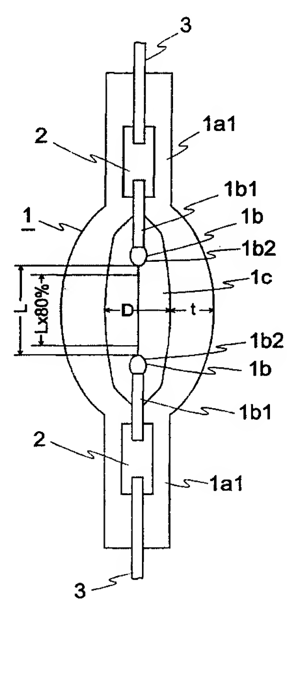

Fig.2

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Description

BACKGROUND OF THE INVENTION

Field of Invention

[0001] The present invention relates to a metal halide lamp substantially not including mercury (Hg), a metal halide lamp apparatus and a vehicle lighting apparatus using the lamp.

Description of Related Art

[0002] Generally, a metal halide lamp is provided with a discharge vessel filled with an ionizable gas filling including a rare gas, a metal halide, and mercury (Hg). Such a metal halide lamp is practical for use in various light fixtures because of its high efficacy and good color rendering properties.

[0003] Particularly, in the view of its high efficacy and a color rendering, it is suitable for such a metal halide lamp to be utilized as a vehicle headlight. When the metal halide lamp is used as a vehicle headlight, it must be able to pass a brightness test. The brightness of the lamp shining on a screen must reach a predetermined luminous flux after a predetermined time has elapsed after the vehicle headlight turned on. According to Japan Electrical Lamp Manufactures Association Standard No. 215 (hereinafter JEL-215), a lamp for a vehicle headlight is required to generate its rated luminous flux of 25% one second after the lamp Fumed on. It is further required to generate its rated luminous flux of 80% four seconds after the lamp turned on.

[0004] The mercury (Hg) of a metal halide lamp having mercury (Hg) and a metal halide, primarily emits about four seconds after the lamp is lit. Four seconds later, the metal halide starts to emit, so that the lamp starts to increase its luminous flux. The luminous efficacy of mercury (Hg) is half of that of the metal halide. Therefore, the lamp must be supplied twice as much power as that of an ordinary lamp in order to increase the luminous flux to an acceptable level within four seconds after the lamp turned on. For example, in case of applying the lamp having mercury (Hg) to the vehicle headlight, the lamp lights at a rated luminous flux of 25% in one second, and the lamp can emit the rated luminous flux of 100% in four seconds. However, color characteristics, e.g., a color rendering property or a chromaticity is not good during the initial few seconds after the lamp started. For example, the lamp has an out of white color region on the chromaticity diagram at the beginning of lamp operation. It takes about ten seconds for the lamp's chromaticity to get into the white color region. Furthermore, for this type of lamp, luminous flux slowly increases at the beginning of lamp operation in comparison with that of a halogen incandescent lamp. If the electrical power is further supplied to the lamp in order to increase luminous flux, it is likely to overshoot the desired steady state level of luminous flux because of increased mercury (Hg) evaporation during the initial second after the lamp turned on. Accordingly, in the view of a initial luminous flux of the lamp, it is difficult for the metal halide lamp having mercury (Hg) to be used as a vehicle headlight.

[0005] A metal halide lamp is disclosed in U.S. Patent 4,594,529 (prior art 1). A gas discharge lamp is suitable for using with a reflector as a vehicle headlight. The gas discharge lamp comprises a lamp envelope made of quart2 glass having an elongate discharge space. Electrodes are arranged near both sides of the an elongate discharge space. Current-supply conductors, connected to respective electrodes, extend outwardly from vacuum-tight seals.

[0006] The lamp envelope is filled with an ionizable gas filling including a rare gas, mercury (Hg), and a metal halide. The lamp envelope has a wall thickness (t) of 1.5mm to 2.5mm, and an inner diameter (D) of 1mm to 3mm at the midway point between the electrodes. The distance (d) between the tips of the electrodes is 3.5mm to 6mm. Each of the electrodes projects a length (1) of 0.5mm to 1.5mm into the lamp envelope. The quantity A (mg) of mercury (Hg) used in the lamp is determined as follows: $0.002^*(d+4^*1)^*D^2 \leq A \leq 0.2\ (d+4^*1)^*D^{1/3}$,wherein the inner diameter (D), the distance (d), and length (1) are expressed in mm. Prior art 1 describes a metal halide lamp, which is horizontally arranged. The lamp operates with high efficiency and contains mercury (Hg) in its bulb. However, mercury (Hg) is harmful to our environment and the amount of mercury used in bulbs should be reduced. Also the arc formed by discharge in the bulb is not vertically spread as desired. Rather, the arc height is contracted. Metal halide lamps not including mercury (Hg) (called a mercury less or a mercury free lamp) are disclosed in Japanese Patent 2,982,198 (prior art 2), Japanese Laid Open Application HEI 6-84,496 (prior art 3), HEI 11-238,488 (prior art 4), or HEI 11-307,048 (prior art 5).

[0007] According to the prior art 2, a metal halide lamp is filled with either scandium (Sc) halide or a rare metal halide and a rare gas, and is ignited by a pulse current. The metal halide lamp described in prior art 3 has a metal halide and a rare gas so that its color characteristics do not change even if a dimmer controls the lamp. According to prior art 4, a metal halide lamp can be configured to further include another kind of metal halide (a secondary metal halide), e.g., magnesium (Mg) halide, in addition to its primary metal halide in order to improve its electrical characteristics. The metal halide lamp of prior art 5 includes yet another metal halide (a third metal halide), e.g., indium (In) or yttrium (Y)

halide, which has an ionization voltage of 5 to 10eV and an operational vapor pressure of $1x10^{-5}$ atm, in addition to scandium (Sc) halide and sodium (Na) halide. The electrodes of this metal halide lamp do not evaporate too much, so that a discharge vessel does not easily blacken.

[0008] In the case of a metal halide lamp not including mercury (Hg), a rare gas primarily slightly illuminates about four seconds after the lamp turned on. The luminous efficacy of the rare gas is lower than that of mercury (Hg). Accordingly, even if the lamp is supplied twice as much power as that of an ordinary lamp in order to increase its luminous flux in four seconds or more, after the lamp turned on, the lamp can not satisfy the aforementioned regulation of JEL-215 sufficiently.

SUMMARY

[0009] The inventions claimed herein describe metal halide lamps, metal halide lamp apparatus, and vehicle lighting apparatus.

[0010] In one embodiment of the invention, a metal halide lamp includes a light-transmitting discharge vessel having a sealed portion, and a pair of electrodes projecting into a discharge space of the vessel. Its (D/L) ratio is in the range of about 0.25 to about 1.5, and a t/L ratio is within about 0.16 to about 1.1, wherein L is an interspace of tips of the electrodes, D is a maximum inner diameter thereof, and t is a maximum wall thickness of the discharge space portion. An ionizable gas filling, which contains a rare gas and a metal halide including at least sodium (Na) or scandium (Sc) and not substantially including mercury (Hg), fills in the discharge vessel. Conductive wires electrically connect to respective electrodes and extend from the discharge vessel.

[0011] The inventions also include a metal halide lamp apparatus. A metal halide lamp apparatus includes a metal halide lamp and a ballast. The ballast has a relation between a filling pressure X (atm) of xenon (Xe), and a maximum electrical power AA (W) according to the following formula:

$$3 < X < 15,\ AA \geq -2.5X+102.5,$$

wherein the maximum electrical power AA (W) is a maximum wattage supplied to the lamp in four seconds after the lamp turned on.

[0012] The inventions presented herein include a vehicle lighting apparatus. A vehicle lighting apparatus includes a metal halide lamp, a reflector accommodating the metal halide lamp, a front cover arranged to an opening of the reflector, and a ballast.

[0013] These and other aspects of the invention are further described in the following drawings and detailed description of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The invention will be described in more detail by way of examples illustrated by drawings in which:

FIGURE 1 is a longitudinal section of a metal halide lamp according to a first embodiment of the present invention;
FIGURE 2 is a side view of the metal halide lamp shown in FIGURE 1;
FIGURE 3 is a cross section of a discharge vessel of the metal halide lamp shown in FIGURE 1;
FIGURE 4 is a graph showing a total luminous flux as a function of lamp operational time;
FIGURE 5 is a longitudinal section of a metal halide lamp according to a second embodiment of the present invention;
FIGURE 6 is a side view of the metal halide lamp shown in FIGURE 5;
FIGURE 7 is a graph showing a total luminous flux as a progress of lamp operational time;
FIGURE 8 is a side view of a metal halide lamp according to a third embodiment of the present invention;
FIGURE 9 is a side view of a metal halide lamp according to a fourth embodiment of the present invention;
FIGURE 10 is a side view of a metal halide lamp according to a fifth embodiment of the present invention;
FIGURE 11 is a side view of a metal halide lamp according to a sixth embodiment of the present invention;
FIGURE 12 is a side view of a metal halide lamp according to a seventh embodiment of the present invention;
FIGURE 13 is a graph showing a total luminous flux as a progress of lamp operational time;
FIGURE 14 is a chromaticity diagram of a vehicle lighting apparatus according to an eighth embodiment of the present invention;
FIGURE 15 is a longitudinal section of a metal halide lamp according to an eleventh embodiment of the present invention;
FIGURE 16 is a side view of a metal halide lamp assembly;

FIGURE 17 is a perspective view of a vehicle lighting apparatus;
FIGURE 18 is a circuit diagram of an electric ballast to start a metal halide lamp; and
FIGURE 19 is another circuit diagram of an electric ballast to start a metal halide lamp.

DETAILED DESCRIPTION

[0015] A first exemplary embodiment of the invention will be explained in detail with reference to FIGURES 1 to 4. A metal halide lamp shown in FIGURE 1 is provided with a discharge vessel 1 having sealed portions 1a1 and electrodes 1b disposed in the discharge vessel 1. Each of molybdenum foils 2 is connected to a respective electrode 1b. Furthermore, each of outer conductive wires 3 is connected to a respective molybdenum foil 2.

[0016] The discharge vessel 1, made of quartz glass, has an ellipsoid-shaped portion 1a surrounding a discharge space 1c, and sealed portions 1a1 continuously formed with the ellipsoid-shape portion 1a. The thickness of the ellipsoid-shape portion 1a may change from portion to portion thereof as appropriate for size, shape, etc.

[0017] Each of electrodes 1b is made of tungsten and includes an electrode rod 1b1 and a tip portion 1b2, the diameter of which is larger than that of the electrode rod 1b1. The other end of each electrode rod 1b1 is embedded in the sealed portion 1a1 to connect to the molybdenum foil 2. Each of electrodes 1b may be the same structure when an alternating current power is supplied to the metal halide lamp.

[0018] When the metal halide lamp is used as a vehicle lighting apparatus, it is preferable that the diameter of the tip portion 1b2 is larger than that of a part of the electrode rod 1b1 embedded in the seal 1a1. In general, a metal halide lamp for a vehicle is turned ON and OFF in many times. Thus, there is substantial current flow through electrode rod 1b1 embedded in the sealed portion 1a1 each time the lamp is turned ON. Therefore, the glass of the discharge vessel 1 may crack at a portion near the embedded electrode rod 1b1, because the electrode rod 1b1 alternately expands and contracts when the lamp is turned ON and OFF. If the outer diameter of the part of the embedded electrode rod 1b1 is made large, the surface area of the part contacting the sealed portion 1a1 becomes large. Therefore, it is easy for a crack to occur. In this embodiment, the glass does not easily crack because the outer diameter of the embedded electrode rod 1b1 is smaller than that of the tip portion 1b2.

[0019] One end of each of outer conductive wires 3 is embedded in the sealed portion 1a1 to connect the molybdenum foil 2. The other end of each of conductive wires 3 extends from the discharge vessel 1. The discharge vessel 1 may be made of a light transmissible substance, e.g., alumina, or ceramics. The discharge vessel 1 may optionally have a transparent film on the inner surface thereof to prevent the glass of the vessel from being contaminated by the filling gas including halogen.

[0020] The discharge vessel 1 is filled with an ionizable filling containing a metal halide and a rare gas. The metal halide includes one or more selected from a group of sodium (Na), scandium (Sc) and other rare earth elements. A halogen may be one or more selected from a group of fluorine (F), chlorine (Cl), bromide (Br), and iodide (I). The amount of metal halides should be in the range of about 5mg to about 110mg per 1cc by a volume of the discharge space 1c. The metal halide lamp may include rare metal halide, e.g., dysprosium iodide (DyI_3) in order to appropriately adapt visible light to a white range in the chromaticity diagram. During operation, the metal halide lamp not including mercury (Hg) has lower pressure of 6 ~ 10 atm of a rare gas than that of the lamp having mercury (Hg). This helps to prevent the lamp's discharge vessel from breaking.

[0021] FIGURE 2 shows dimensions of the metal halide lamp. Reference characters are defined as follows:

L is an interspace of tips of electrodes 1b.
D is a maximum inner diameter of the discharge vessel 1.
t is a maximum wall thickness of the ellipsoid-shape portion 1a.

[0022] It is suitable that the maximum inner diameter (D) and the maximum Thickness (t) are in a range of 80% of the interspace (L) shown in FIGURE 2 except for adjacent to each tip of the electrodes. In order to increase the temperature of the discharge vessel 1, the discharge vessel 1 is formed so that it's walls are close to an arc discharge generated within the vessel. However, it is not easy to increase the temperature adjacent to the electrode tips, i.e., within 10% of the interspace (L) between the tips. Because, the arc discharge tends to occur apart from both electrode tips, the temperature around the tips 1b2 does not easily increase, comparatively.

[0023] When the D/L ratio is in the range of about 0.25 to about 1.5, the arc discharge of the discharge vessel can increase the temperature of the discharge vessel 1. The center of the arc discharge is adjacent to the inner surface of the discharge vessel 1 so that heat of the arc discharge increasingly conducts to the discharge vessel 1. Therefore, the temperature of the discharge vessel 1 rises appropriately and uniformly. The preferred D/L ratio is in a range of about 0.30 to about 1.05. A range of about 0.45 to about 0.9 is even more preferable. If the D/L ratio is over about 1.5, the heat conduction does not increase sufficiently. When the D/L ratio is under about 0.25, the temperature of the discharge vessel increases excessively. Then, discharge vessel 1 expands inappropriately. If the discharge vessel is

made of quartz glass, its transparency decreases because of crystallizing.

[0024] When the t/L ratio is about 0.16 to about 1.1, the temperature of the discharge vessel 1 increase quickly and properly. In general the t/L ratio should be in the range of about 0.21 to about 0.77. A range of about 0.31 to about 0.57 is more preferable. If the t/L ratio is over about 1.1, a heat capacity increases excessively. When the t/L ratio is under about 0.16, the wall thickness of the discharge vessel 1 becomes too thin and heat conducted from the arc discharge, diffuses outwardly through the discharge vessel 1.

[0025] A metal halide lamp, according to this embodiment, that is supplied with electrical power of 100W or less, is arranged horizontally. When the lamp operates, a liquid halide H shown in FIGURE 3 adheres to the inner surface of the discharge vessel 1 over an angular area of about +80 degrees to about -80 degrees from a vertical line through the axis of discharge vessel 1.

[0026] As the temperature of the discharge vessel 1 rises appropriately and uniformly, the temperature of the liquid halide H rises, so that the metal halide evaporates quickly and a luminous flux rises quickly. When the metal halide contains about 30 ~ about 55mg per 1cc by a volume of the discharge space, the luminous flux rises quickly.

[0027] If a region of the liquid halide H shown in FIGURE 3 becomes larger compared with an area of the discharge space, visible light passing through the region changes colors. Therefore, in order to irradiate a good color of visible light from the discharge vessel, it is preferable that the metal halide constitutes about 5 ~ about 35mg/cc by a volume of the discharge space.

[0028] According to an experiment, the amount of the adhering metal halide increases in proportion to the wall thickness of the discharge vessel 1. When a quantity q (mg/cc) of the metal halide in the discharge vessel is as follows:

$$q \leq 71.4 / t,$$

wherein

q is a quantity (mg) per 1cc of the discharge space, and
t is a maximum thickness adjacent to the center of the discharge vessel, the visible light passing through the region does not easily change colors.

[0029] The area adhered by liquid halide on the inner surface of the discharge vessel 1 is preferably the area defined by an angle of about +80 degrees to about -80 degrees from a vertical line passing through the horizontal axis of vessel 1. This angular region applies during lamp operation. However, it may be measured when the lamp is not operating because the region occupied by the liquid halide is not significantly different when the lamp is not being operated.

[0030] In general, since the metal halide adhering to the inner surface changes into liquid phase during lamp operation, visible light passing through this region changes colors due to the liquefied metal halide. For example, the metal halide of Sc-Na-I composition changes visible light into green or yellow, so that the chromaticity is not suitable for a vehicle lighting apparatus. In this case, a screen is disposed along a region corresponding to the liquefied metal halide in the discharge vessel. Light (not needed) passing through the metal halide is blocked by the screen. The quantity q (mg/cc) of the metal halide in the discharge vessel may be as follows: $q \leq 30.6 / t$. In this case, the region adhering liquid halide is decreased, so that the screen can sufficiently block the needless light.

[0031] The lamp may further include another metal halide (a secondary metal halide) in order to improve the lamp's electrical characteristics. The secondary metal halide, disclosed in Japanese Laid Open Application HEI 11-238488 can use one metal or more selected a group of magnesium (Mg), iron (Fe), cobalt (Co), chromium (Cr), zinc (Zn), nickel (Ni), manganese (Mn), aluminum (Al), antimony (Sb), beryllium (Be), rhenium (Re), gallium (Ga), titanium (Ti), zirconium (Zr), hafnium (Hf), and tin (Sn). However, occasionally, a luminous intensity of the lamp including the secondary metal halides rises slowly, because a film formed on the inner surface of the discharge vessel diffuses visible light.

[0032] The interspace (L) between the tips of electrodes is preferable to about 6mm or less. When the distance (L) is over about 6mm, it is difficult to position the entire distance (L) at the focus of a reflector. Therefore, visible light can not appropriately reflect on the inner surface of the reflector, and brightness may reduce.

[0033] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Example 1.

Example 1

[0034]

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter (D)	About 4.5mm
Interspace between tips (L)	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
D/L ratio	About 1.07
t/L ratio	About 0.24
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.5mg
Sodium iodide (NaI) as metal halide	About 3.5mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 5atm

[0035] FIGURE 4 is a graph of total luminous flux as a function of lamp operational time. The horizontal axis indicates lamp operational time beginning when the lamp is turned ON. The vertical axis indicates a correlated total luminous flux. Line A designates the total luminous flux of Example 1. Line B designates that of a Test Sample, which is constructed the same in Example 1 except for being filled with mercury (Hg) instead of zinc iodide (ZnI_2). Example 1 (line A) exhibits a rapid increase the total luminous flux within one second after the lamp started.

[0036] A second exemplary embodiment of the invention will be explained in detail referring to FIGURES 5 to 7. The same reference numerals refer to like or similar parts to those already described and therefore detailed explanation of those pans will not be provided. In this embodiment, a discharge space 1c of a discharge vessel 1 is formed into a near cylindrical shape as shown in FIGURES 5 and 6. Therefore, an arc discharge occurs along the cylindrical shape.

[0037] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Example 2.

Example 2

[0038]

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 3mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
D/L ratio	About 0.71
t/L ratio	About 0.42
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.5mg

(continued)

Compositions of ionizable gas filling	
Sodium iodide (NaI) as metal halide	About 3.5mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 5atm

[0039] The arrangement of example 2 also provides a quick increase in the total luminous flux within about one second after the lamp started, as plotted in

FIGURE 7.

[0040] A third exemplary embodiment of the invention will be explained in detail referring to FIGURE 8, which shows a side view of a metal halide lamp. The same reference numerals refer to like or similar parts to those already described in FIGURE 6 and therefore detailed explanation of those pans will not be provided. In this embodiment, starting points of the discharge arc on both electrode tips will be located on one side of the axis of the electrodes.

[0041] An arc discharge 4, which occurs between discharge starting points 4a at tips 1b2 of electrodes 1b, is adjacent to the inner wall of the discharge vessel 1. Generally, when the metal halide lamp arranged horizontally is started, the arc discharge 4 tends to curve upward into the discharge space 1c. Accordingly, the discharge starting points 4a transfer to upward of the tips 1b2 of the electrodes 1b. A distance between the transferred arc discharge and the inner surface is defined as Dc/2. As a result, it is seen that the inner diameter (Dc) of the discharge vessel is made shorter. The amended inner diameter of the discharge vessel is a length of Dc. Because L and t were explained already, further explanation is not provided. When the tips 1b2 of the electrodes 1b are made larger, the arc discharge transforms conspicuously. In this case, the Dc/L ratio is in the range of about 0.25 to about 0.96, and the t/L ratio is within a range of about 0.16 to about 1.1. It is more preferable that the Dc/L ratio has a range of about 0.45 to about 0.9, and the t/L ratio has within about 0.31 to about 0.57.

[0042] A fourth exemplary embodiment of the invention will be explained in detail referring to FIGURE 9, which shows a side view of a metal halide lamp. In this embodiment, a discharge space 1c is narrowly formed in order to prevent a discharge vessel 1 from expanding. A lamp power P (W) is 100W or less. A relation of both an inner diameter ID (mm) and an outer diameter OD (mm) of the discharge vessel 1 and the lamp power (P) is expressed by the following formula:

$$(OD - ID) * ID / P > 0.21.$$

[0043] The discharge vessel 1 is filled with an ionizable gas filling, which contains a metal halide and a rare gas. The metal halide includes at least sodium (Na) and scandium (Sc). The rare gas includes at least xenon (Xe). When the metal halide lamp, arranged horizontal, lights up, an arc discharge tends to curve to upward in the discharge space 1c.

[0044] When the lamp is used as a vehicle lighting apparatus, it is preferable that the arc discharge does not curve in the upward direction. Japanese Laid Open SHO 59-111244 discloses a technique for reducing a curve of an arc discharge by forming the discharge space into small size. In this case, the arc discharge comes near to the inner surface of a discharge vessel, so that a heat of the arc discharge conducts to the discharge vessel too much. Accordingly, the discharge vessel occasionally expands due to the heat. However, the shape of the discharge vessel formed according to the above formula is useful in order to avoid problems due to expansion of the discharge vessel.

[0045] The metal halide lamp of this embodiment may further comprise the above-mentioned secondary metal halide. That is, the metal halide includes sodium (Na), scandium (Sc), and the secondary metal halide. Besides, xenon (Xe) as the rare gas filling pressure A (atm) at 25 degrees centigrade and the interspace L (mm) is satisfied by a following formula: $1.04 \leq A/L \leq 4$. According to the formula, a lamp current and a start voltage can be appropriately set up. The A/L ratio is more preferable in a range of about 1.4 to about 2.78. If the A/L ratio is under about 1.04, the lamp current tends to increase too much, so that mass of the ballast becomes large. When the A/L ratio is over about 2.78, the filling pressure A of xenon (Xe) rises highly, so that a starting property becomes slightly bad because of a start voltage rising.

[0046] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Examples 3 to 4.

Example 3

[0047] The shape of the discharge vessel is the same as the first embodiment in FIGURE 1.

Dimensions of discharge vessel	
Outer diameter at center (OD)	About 6.5mm
Maximum inner diameter (ID)	About 4.5mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.5mg
Sodium iodide (NaI) as metal halide	About 3.5mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 8atm
A/L ratio	About 1.9

Example 4

[0048] The shape is the same as the second embodiment in FIGURE 6. The discharge space is formed into a cylindrical shape. Compositions of the ionizable gas filling is the same in Example 3.

Dimensions of discharge vessel	
Outer diameter at center (OD)	About 6.5mm
Maximum inner diameter (ID)	About 3mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm

[0049] A fifth exemplary embodiment of the invention will be explained in detail referring to FIGURE 10, which shows a side view of a metal halide lamp. In this embodiment, A lamp power (P) is 100W or less. Discharge vessel 1 is filled with an ionizable gas filling, which contains a metal halide, a secondary metal halide and a rare gas. A metal halide includes at least sodium (Na) and scandium (Sc). Reference L is the above-mentioned distance between tips 1b2 of electrodes 1b.

[0050] The inner surface of a discharge space 1c shown in FIGURE 10, is formed into an approximately elliptic shape. Furthermore, both sides of the inner surface are formed into a conic shape. An extending line (12) from a cone and a tangential line (14) of the center of the ellipse cross each other at a point P1. The extending lines (12) in opposite direction of the point P1 intersect at a point P2. A length p1 is a distance from the point P1 to P2. A reference p2 is a length projecting into a discharge space 1c, or a distance between the point P2 and a tip 1b2 of an electrode 1b. The length p1 and p2 relate to a following formula:

$$0.6 \leq p2/p1 \leq 1.7.$$

Each of electrodes 1b, whose one end is embedded in sealed portions 1a1 through the apex of the cone, is located on a longitudinal axis (13). The p2/p1 ratio may be in a range of about 1.0 to about 1.3.

[0051] When the p2/p1 ratio is under about 0.6 and dimensions of the discharge space 1c are constant, the point P2 tends to shorten and the interspace (L) between the tips 1b2 of the electrodes 1b becomes long. Therefore, a temperature of the discharge vessel 1 around the electrodes 1b increases too much, so that the discharge vessel 1 may expand occasionally.

[0052] When the interspace (L) is constant instead of the dimensions of the discharge space 1, the discharge space 1c becomes small. In this case, the distance between the electrodes 1b and the inner surface of the discharge vessel 1 becomes short, so that the temperature of the discharge vessel 1 increases sharply. Accordingly, the discharge vessel 1 may expand occasionally.

[0053] If the p2/p1 ratio is over 1.7 and the dimensions of the discharge space 1c are constant, the interspace (L) becomes short. When the interspace (L) is constant instead of the dimensions of the discharge space 1c, the discharge space becomes large. In this case, a distance between the electrodes 1b and the inner surface of the discharge vessel 1 becomes long, so that the temperature of around the length p1 of the discharge vessel 1 increases slowly. As a result, luminous flux also increases slowly.

[0054] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Examples 5 to 6.

Example 5

[0055] The shape of the discharge vessel is the same as the first embodiment in FIGURE 1.

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 4.5mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
p2/p1 ratio	About 1
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.5mg
Sodium iodide (NaI) as metal halide	About 3.5mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 5atm

Example 6

[0056] The shape of the discharge vessel I is the same as the first embodiment in FIGURE 1. Compositions of the ionizable gas filling is the same in Example 5.

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 3mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of the electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
p2/p1 ratio	About 1.3

[0057] A sixth exemplary embodiment of the invention will be explained in detail referring to FIGURE 11, which shows a side view of a metal halide lamp. In this embodiment, an upper and a lower shapes of the inner surface of a discharge vessel 1 are not symmetrically formed with respect to the axis (13) of electrodes 1b. That is, a distance between the axis (13) and an upper inner surface 1c1 is longer than that between the axis (13) and lower inner surface 1c2. The ratio Hd/L is in a range of about 0.15 to about 0.5, wherein Hd is a distance between the axis (13) and the lower inner

surface 1c2, L is a distance between tips 1b2 of electrodes 1b. The Hd/L ratio is preferably in a range of about 0.22 to about 0.45.

[0058] An arc discharge generating in the discharge vessel 1 makes a temperature of the discharge vessel 1 increase, because the center of the arc discharge 1 is adjacent to the lower inner surface 1c2. Accordingly, a heat conduction from the arc discharge to the lower side of the discharge vessel 1 increases, so that a temperature of the discharge vessel 1 rises appropriately. The heat promotes an evaporation of a liquid halide adhering on the lower inner surface 1c2, so that a luminous flux increases quickly. When the Hd/L ratio is less than about 0.15, the heat conduction becomes too much, so that the discharge vessel 1 may occasionally expand. Furthermore, if the Hd/L ratio is larger than about 0.5, it is difficult to increase the temperature of the discharge vessel 1.

[0059] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Example 7.

Example 7

[0060]

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 4.5mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
Hd	About 1.5mm
Hd/L	About 0.36
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 1mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 5atm

[0061] A seventh exemplary embodiment of the invention will be explained in detail referring to FIGURE 12, which shows a side view of a metal halide lamp. In this embodiment, an upper and a lower shape of the inner surface of a discharge vessel 1 are not symmetrically formed with respect to the axis (13) of electrodes 1b. That is, a distance between the axis (13) and an upper inner surface 1c1 is shorter than that of between the axis (13) and a lower inner surface 1c2. The ratio Hu/L is in a range of about 0.15 to about 0.5, wherein Hu is a distance between the axis (13) and the upper inner surface 1c1, L is a distance between tips 1b2 of electrodes 1b. The Hu/L ratio is preferably in a range of about 0.22 to about 0.45.

[0062] An arc discharge generated in the discharge vessel 1 causes the temperature of the discharge vessel 1 to increase because the center of the arc discharge is adjacent to the upper inner surface 1c1. Accordingly, heat conduction from the arc discharge to the discharge vessel 1 increases, so that the temperature of the discharge vessel 1 rises. The heat promotes evaporation of liquid halide adhering on the lower inner surface 1c2, so that luminous flux increases quickly. When the Hu/L ratio is less than about 0.15, heat conduction is too high, and the discharge vessel 1 may occasionally expand. Furthermore, if the Hu/L ratio is larger than about 0.5, it is difficult to increase the temperature of the discharge vessel 1.

[0063] Dimensions of the discharge vessel 1 and compositions of the ionizable gas filling will be described below in Example 8.

Example 8

[0064]

Dimensions of discharge vessel	
Outer diameter of center	About 6.5mm
Maximum inner diameter	About 4.5mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.6mm
Hu	About 1.5mm
Hd/L	About 0.36
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 1mg
Zinc iodide (ZnI_2) as secondary metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 5atm

[0065] An eighth exemplary embodiment of the invention is similar to the second embodiment shown in FIGURE 5. A discharge space 1c is formed into a nearly cylindrical shape. In the following Example 9-A1 and 9-A2, an ionizable gas filling does not contain a secondary metal halide. Test Sample 9-B also dose not include the secondary metal halide but includes mercury (Hg).

[0066] Detailed compositions of a discharge vessel and compositions of the ionizable gas filling will be described below in Example 9-A1, 9-A2 and Test Sample 9-B.

Example 9-A1

[0067]

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 3mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.7mm
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 1mg
Dysprosium iodide (DyI_3) as metal halide	About 0.05mg
Xenon (Xe) gas as rare gas	About 8atm

Example 9-A2

[0068] Dimensions of the discharge vessel are the same in Example 9-A1.

Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg,
Sodium iodide (NaI) as metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 8atm

Test Sample 9-B

[0069] Dimensions of the discharge vessel are the same in Example 9-A1.

Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 0.6mg
Xenon (Xe) gas as rare gas	About 8atm
Mercury (Hg)	About 1mg

[0070] Table 1 describes respectively a lamp voltage, a total luminous flux, a general color rendering index (Ra), and a color temperature. Each lamp in Table 1 has a lamp power of 40W using a ballast generating a frequency of 200Hz. This embodiment is suitable for use as a vehicle lighting apparatus because produces the needed total luminous flux within the prescribed time.

[0071] FIGURE 13 is a graph showing a total luminous flux as a progress of lamp operational time. The horizontal axis indicates lamp operational time in seconds from the initial application of power. The vertical axis indicates a correlated total luminous flux. Lines E and F designate the total luminous flux of Example 9-A1 and Test Sample 9-B, respectively.

Example 9-A1 can quickly increase the total luminous flux within one second after the lamp started. The total luminous flux of Example 9-A2 also is the same as Example 9-A1.

Table 1

Lamps	Example 9-A1	Example 9-A2	Test Sample 9-B
(1)Lamp voltage (V)	35	33	80
(2)Total luminous flux (lm)	3400	3450	3600
(3)General color rendering index (Ra)	71	68	63
(4)Color temperature (K)	4320	4040	4240

[0072] The above (3) general color rendering index (Ra) and (4) color temperature (K) are as follows, when a lamp power is changed in the range of about 15W to about 40W.

Table 2

	Example 9-A1		Example 9-A2		Test Sample 9-B	
Lamp power	(3)(Ra)	(4)(K)	(3)(Ra)	(4)(K)	(3)(Ra)	(4)(K)
15W	60	4580	60	4280	40	5660
20W	65	4520	62	4220	45	5370
25W	66	4450	63	4150	52	5130
30W	67	4390	64	4120	56	4660
35W	69	4350	66	4080	61	4430
40W	71	4320	68	4040	63	4240

[0073] According to Examples 9-A1 and 9-A2 in Table 2, both the general color rendering index (Ra) and the color

temperature (K) do not change too much, even if the lamp power is outside the range of about 15W to about 40W. However, Test sample 9-B cannot be prevented from decreasing the above (3) general color rendering index (Ra) and (4) color temperature (K).

[0074] In this case, a test was carried out as follows: after each of the lamps was operated at a lamp power of 30W for 30 minutes, each lamp was turned OFF. Ten seconds later, each lamp was turned on at a re-starting voltage again. The re-starting voltage is indicated in Table 3.

Table 3

	Example 9-A1	Example 9-A2	Test Sample 9-B
Re-starting voltage (KV)	8.8	9.2	16.3

[0075] According to Table 3, Examples 9-A1 and 9-A2 are able to re-start easily at a low re-starting voltage in comparison with Test Sample 9-B having mercury (Hg). However, when the lamp of Test Sample 9-B re-starts, mercury (Hg) still evaporates in the discharge vessel at high pressure. Therefore, the re-starting voltage of the lamp tends to become higher, so that the lamp can not easily light up by the supplied voltage.

[0076] FIGURE 14 is a chromaticity diagram of a vehicle lighting apparatus using lamps of Examples 9-A1 and Test Sample 9-B. The vehicle lighting apparatus is supplied with a lamp power of 80W at the beginning of a lamp starting. After the lamp turned on, the lamp power is gradually reduced by a power controlling means (not shown), so that the lamp power is regulated at 40W. A chromaticity of the specific point of the vehicle lighting apparatus is plotted on a chromaticity diagram, while changing the lamp power from 80W to 40W. The result of Example 9-A and Test sample 9-B is shown in FIGURE 14.

[0077] In FIGURE 14, the horizontal and vertical axes respectively indicate X and Y chromaticity coordinates. A region surrounded by a frame line designates a white color part relating to the vehicle lighting apparatus, which is regulated by Japanese Industrial Standard (JIS). Line C and D respectively point out the chromaticities of Example 9-A1 and Test sample 9-B. Numbers around the line C or D stand for operational progress time (seconds) after the lamp started. According to FIGURE 14, the chromaticity of Example 9-A1 is appropriate to the vehicle lighting apparatus regulation at the beginning of the lamp starting because of sodium (Na), scandium (Sc), and xenon (Xe) illuminating in the discharge vessel. However, the chromaticity of Test Sample 9-B becomes out-of-regulation of JIS at the beginning of the lamp starting because of mercury (Hg) illuminating in the discharge vessel. It takes about twenty three seconds for the chromaticity to become within the range specified by the regulation.

[0078] The reports of additional testing follow. Each of lamps of Example 9-A1 and Test Sample 9-B was started at three different power levels, namely, 80W, 90W, and 100W. After one and four seconds, total luminous flux of each lamp was measured at each lamp power. The luminous fluxes of both Example 9-A1 and Test Sample 9-B were respectively compared with those of the lamps which constantly light up at 40W. Results are presented in Table 4.

Table 4

	Total luminous flux (%)			
	One second later		Four seconds later	
Lamp power of starting	Example 9-A1	Test Sample 9-B	Example 9-A1	Test Sample 9-B
80W	32	25	70	78
90W	42	28	75	120
100W	51	35	82	180

[0079] According to Example 9-A1 in Table 4, after the lamp turned on, one second later, xenon (Xe), scandium (Sc), sodium (Na), and dysprosium (Dy) illuminate in one second. In Test Sample 9-B, both xenon (Xe) and mercury (Hg) illuminate at low efficiency, so that the total luminous flux of Test Sample 9-B decreases. However, four seconds later, the luminous flux of Test sample 9-B increases, because mercury (Hg) evaporates sufficiently. In Test Sample 9-B, when the lamp is supplied 100W of lamp power, the total luminous flux, i.e., 180% is out-of regulation of JIS.

[0080] A ninth exemplary embodiment of this invention will be explained below. In this embodiment, the discharge-vessel shape is the same as that of the second embodiment in FIGURE 5. Xenon (Xe) gas fills in a discharge vessel at 8atm pressure. A metal halide in Table 5 filling the discharge vessel is different from that of the second embodiment.

Table 5

Metal halide of filling	Example 10-C1	Example 10-C2	Example 10-C3	Example 10-C4	Example 10-C5
Scandium iodide (ScI_3)	0.2mg	0.2mg	0.2mg	0.2mg	0.2mg
Sodium iodide (NaI)	1mg	1mg	1mg	1mg	0.4mg
Thulium iodide (TmI_3)	0.05mg	-	-	-	-
Neodymium iodide (NdI_3)	-	0.05mg	-	-	-
Cerium iodide (CeI_3)	-	-	0.05mg	-	-
Holmium iodide (HoI_3)	-	-	-	0.05mg	-
Lithium iodide (LiI)	-	-	-	-	0.5mg

[0081] Followings in Table 6 are lamp voltage, total luminous flux, general color rendering index (Ra), and color temperature, wherein the lamps (Example 10-C1 to C5) consumes 40W of lamp power during lamp operation using a ballast generating frequency of 200Hz. This embodiment is suitable for use as a vehicle lighting apparatus because it satisfies the total luminous flux requirements.

Table 6

Lamp	Example 10-C1	Example 10-C2	Example 10-C3	Example 10-C4	Example 10-C5
(1)Lamp voltage (V)	34	33	32	32	30
(2)Total luminous flux (lm)	3420	3340	3480	3350	3210
(3)General color rendering index (Ra)	69	71	69	72	73
(4)Color temperature (K)	4410	4370	4450	4340	3820

[0082] A tenth exemplary embodiment of the invention will now be explained. In this embodiment, a relation between a filling pressure X (atm) of xenon (Xe) and a maximum electrical power AA (W) is provided with a following formula:

$$3 < X < 15,\ AA \geq -2.5X + 102.5,$$

in order to achieve a luminous intensity of 8000cd at a representative point of a front surface of a vehicle light apparatus in four seconds, after the lamp lit up, wherein the maximum electrical power AA (W) is a maximum wartage supplied to the lamp in four seconds, after the lamp lit up.

[0083] The maximum electrical power AA (W) is in proportion to the filling pressure X (atm), because xenon (Xe) almost emits light four seconds later in comparison with metal halide having low vapor pressure. Besides, a luminous flux of xenon (Xe) is originally in proportion to both the filling pressure X (atm) and the electrical power AA (W), so that it is easily to adjust the luminous flux. Examples 11-1 to 11-7 are described as follows.

Example 11-1

[0084] The shape of a discharge vessel is the same as that of the second embodiment in FIGURE 6. The discharge space is nearly a cylindrical shape.

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 3mm
Interspace between tips	About 4.2mm
Diameter of electrode rod	About 0.4mm
Length of electrode rod	About 7mm
Maximum diameter of electrode	About 0.7mm
Compositions of ionizable gas filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 1mg
Dysprosium iodide (DyI_3) as metal halide	About 0.05mg
Xenon (Xe) gas as rare gas	About 3atm

Example 11-2 to 11-7

[0085] Each of dimensions of discharge vessels in Examples 11-2 to 11-7 is the same in Example 11-1. Compositions of an ionizable gas filling is also the same in Example 11-1 except a pressure of xenon (Xe) gas.

Lamps	Pressure of xenon (Xe) gas
Example 11-2	5atm
Example 11-3	7atm
Example 11-4	9atm
Example 11-5	11atm
Example 11-6	13atm
Example 11-7	15atm

[0086] The above formula is introduced by using both a filling pressure X (atm) of xenon (Xe) and a lamp power (W) of starting in Table 7. Each of Examples 11-1 to 11-7 in Table 7 shows lamp powers (W) of starting and xenon (Xe) gas pressure (atm), which can obtain a luminous intensity of 8000cd in four seconds, after the lamp lit up. Each lamp has a lamp power of 40W using a ballast generating frequency of 200Hz. A vehicle lighting apparatus is required a luminous intensity of 8000cd in four seconds, after the vehicle lighting apparatus turned on.

Table 7

Lamps	Xenon (Xe) gas Pressure (atm)	Lamp Power (W) of starting
Example 11-1	3	95
Example 11-2	5	90
Example 11-3	7	85
Example 11-4	9	80
Example 11-5	11	75
Example 11-6	13	70
Example 11-7	15	65

[0087] An eleventh exemplary embodiment of the invention will be explained hereinafter referring to FIGURE 15, which shows a longitudinal section of a metal halide lamp. Similar reference characters designate identical or corre-

sponding elements of the second embodiment in FIGURE 6. Therefore, detail explanations will not be provided. This embodiment is different from the second embodiment at the point that the lamp is supplied direct current power. That is, one of electrodes is an anode EA, the other is a cathode EK. The anode EA comprises an electrode rod 1b1 having a diameter of 0.4mm and a large tip portion 1b2 having a diameter of 0.9mm. The cathode EK has an electrode rod 1b1 having a diameter of 0.4mm. Followings are Example 12-D1, 12-D2, and Test Sample 12-E.

Example 12-D1

[0088] A shape of the discharge vessel 1 is the same in FIGURE 6. The discharge space 1c is nearly a cylindrical shape.

Dimensions of discharge vessel	
Outer diameter at center	About 6.5mm
Maximum inner diameter	About 3mm
Interspace between tips	About 4.2mm
Diameter of a rod of anode	About 0.4mm
Length of a rod of anode	About 7mm
Diameter of large tip portion of anode	About 0.9mm
Diameter of a rod of cathode	About 0.4mm
Length of a rod of cathode	About 7mm
Compositions of ionizable filling	
Scandium iodide (ScI_3) as metal halide	About 0.2mg
Sodium iodide (NaI) as metal halide	About 1mg
Dysprosium iodide (DyI_3) as metal halide	About 0.05mg
Xenon (Xe) gas as rare gas	About 8atm

Example 12-D2, 12-D3, and Test Sample 12-E

[0089]

	Example 12-D2	Example 12-D3	Test Sample 12-E
Dimensions of discharge vessel	The same in Example 12-D1	The same in Example 12-D1	The same in Example 12-D1
Compositions of ionizable gas filling			
Scandium iodide (ScI_3) as metal halide	0.2mg	0.2mg	0.2mg
Sodium iodide (NaI) as metal halide	0.6mg	0.6mg	0.6mg
Xenon (Xe) gas as rare gas	8atm	8atm	8atm
Dysprosium iodide (DyI_3) as metal halide	-	0.6mg	-
Mercury (Hg)	-	-	1mg

[0090] In this case, a color temperature is measured at around the anode EA and the cathode EK of the lamp, when the lamp is ignited at direct current supply of 40W-lamp power. Results are as follows in Table 8.

Table 8

	A color temperatures (K)	
Lamp	Around anode (EA)	Around cathode (EK)
Example 12-D1	4520	4150
Example 12-D2	4210	3840
Example 12-D3	4320	3950
Test Sample 12-E	5330	3720

[0091] According to Examples 12-D1 to 12-D3 in Table 8, the color temperature of adjacent to the anode (EA) is similar to that of the cathode (EK) comparatively, so that it is suitable for the vehicle lighting apparatus.

[0092] A lamp-life test was conducted by means of a conventional method, which is described by the JEL-215 appendix 4, 1998. An abstract of the method is that the test lamp is flashed ten times every one cycle having two hours. According to a result of the life test, about 70% of following Example 13-F were able to accomplish 2000 cycles, however, all of following Test sample 13-G cracked at sealed portions adjacent to the molybdenum foils connected to the anode EA, in 2000 cycles.

[0093] Detail dimensions of a discharge vessel and compositions of an ionizable gas filling will be described below in Example 13-F and Test Sample 13-G.

Example 13-F, and Test Sample 13-G

[0094] Both Example 13-F and Test Sample 13-G are manufactured 20 each.

	Example 13-F	Test Sample 13-G
Dimensions of discharge vessel	The same in Example 8-D1	The same in Example 13-F
Compositions of ionizable filling		
Scandium iodide (ScI_3) as metal halide	0.2mg	0.2mg
Sodium iodide (NaI) as metal halide	1mg	1mg
Dysprosium iodide (DyI_3) as metal halide	0.05mg	0.05mg
Zinc iodide (ZnI_2) as secondary metal halide	-	0.4mg
Xenon (Xe) gas as rare gas	8atm	8atm

[0095] Next, dimensions of a discharge vessel and compositions of the ionizable gas filling will be described below in Example 14-H, Test Sample 14-I1 and 14-I2 in order to compare a luminous intensity (cd) in four seconds after lamps turning on.

Example 14-H, Test Sample 14-I1, and 14-I1

[0096]

	Example 14-H	Test Sample 14-I1	Test Sample 14-I2
Dimensions of discharge vessel		The same in Example 14-H	The same in Example 14-H
Outer diameter at center	6.5mm	-	-
Inner maximum diameter	3mm	-	-
Interspace between tips	4.2mm	-	-
Diameter of electrode rod	0.4mm	-	-
Length of electrode rod	7mm	-	-
Diameter of large tip portion	0.9mm	-	-

(continued)

	Example 14-H	Test Sample 14-I1	Test Sample 14-I2
Compositions of ionizable filling			
Scandium iodide (ScI_3) as metal halide	0.2mg	0.2mg	0.2mg
Sodium iodide (NaI) as metal halide	1mg	1mg	1mg
Dysprosium iodide (DyI_3) as metal halide	0.05mg	-	-
Zinc iodide (ZnI_2) as secondary metal halide	-	0.4mg	-
Manganese iodide (MnI_2) as secondary metal halide		-	0.4mg
Xenon (Xe) gas as rare gas	8atm	8atm	8atm

[0097] A total luminous flux in steady-state, a total luminous flux four seconds later, and a luminous intensity are described in Table 9 in four seconds after the lamps, which has a lamp power of 40W using a ballast generating frequency of 200Hz, turned on. In this embodiment, the total luminous flux (lm) and the luminous intensity (cd) in Example 14-H are suitable for a vehicle lighting apparatus.

Table 9

Lamps	Example 14-H	Test Sample 14-I1	Test Sample 14-I2
Total luminous flux (lm) in steady-state	3400	3320	3350
Total luminous flux (lm), four Seconds later	2560	2830	2650
Luminous intensity (cd), Four seconds later	12900	7800	8300

[0098] Referring to FIGURE 16, an exemplary embodiment of a metal halide lamp assembly will be described hereinafter. The metal halide lamp assembly shown in FIGURE 16 is provided with an above-mentioned metal halide lamp 10 accommodated an outer bulb 5, and a lamp cap 6 connecting to a conductive wire 7 having an electrical insulator. The assembly can be used as part of a vehicle lighting apparatus. The outer bulb 5 can cut off ultraviolet rays. Air filling in the outer bulb 5 may flow outwardly. The outer bulb 5 may be a vacuum or it may be filled with an inert gas.

[0099] When a metal halide lamp assembly is used in a vehicle lighting apparatus, the apparatus must be able to pass a brightness on a screen test which indicates that required levels of luminous flux can be achieved within predetermined times after the vehicle lighting apparatus turned on. For example, according to JEL-215, the lamp for the vehicle lighting apparatus has a rated luminous flux of 25% in one second after the lamp turned on, and has the rated luminous flux of 80% in four seconds after the lamp turned on. After the lamp lit up, rare gas immediately and primarily illuminates. Luminescence metals comprising metal halide illuminates partially. After a while, luminescence metals illuminate sharply, so that luminous flux increases in proportion to the luminescence. Eventually, the lamp lights up stably. The lamp may light up a rated luminous flux of 25% or more in one second after the lamp lit up by adjusting the power supply. Particularly, in 0.3 seconds after the lamp started, a rate of increase of the luminous flux becomes remarkably high, i.e., several times or more in comparison with that of the lamp including mercury (Hg).

[0100] A vehicle lighting apparatus using a metal halide lamp is shown in FIGURE 17. The lighting apparatus has a reflector 11, and a front cover 12 made of transparent plastics. The front cover 12, which can control a light generated from the lamp, is disposed at an opening of the reflector 11 in an airtight arrangement. The reflector 11, made of plastics, is shaped into a deformed parabolic mirror, and accommodates the lamp.

[0101] FIGURE 18 shows a circuit diagram of the first embodiment of an electric ballast to start a metal halide lamp, such as the ones previously described. The circuit arrangement comprises a direct current (DC) power supply 21, a chopper circuit 22, a controlling means 23, a lamp current detecting means 24, a lamp voltage detecting means 25 for detecting a lamp voltage, and an igniter applying a pulse voltage of 20KV to a metal halide lamp.

[0102] The DC power supply may utilize a battery, or a full-wave rectifier to convert AC power supply to DC. The chopper circuit 22 transforms a DC voltage into a required output voltage. The controlling means 23 lets the chopper circuit 22 generate three times of a rated lamp current. After the lamp lit up, the lamp current is lowered so as to become

the rated lamp current by the chopper circuit 22. The controlling means 23 receives detected signals generated by the lamp current detecting means 24 and the lamp voltage detecting means 25, whose detecting range can be set up to 60V or less. The lamp voltage can be decreased in comparison to that of a metal halide lamp having mercury (Hg).

[0103] A metal halide lamp not including mercury (Hg) tends to have a lower lamp voltage. The lamp loses electrical energy at the electrodes. Generally, such energy loss is related to the anode and cathode drop voltage. The electrode drop voltage of the general metal halide lamp is about 15V. The lamp voltage of the metal halide lamp including mercury (Hg) is about 85V. The rate of electrode loss is 17.6%. However, the lamp voltage of the metal halide lamp not including mercury (Hg) is about 35V. The electrode drop voltage of the lamp not including mercury (Hg) is about 7V. The rate of electrode loss is 20%. Accordingly, a lamp efficacy of the metal halide lamp not including mercury (Hg) is almost the same as that of the lamp including mercury (Hg). Since the lamp voltage lowers, an output voltage, which is measured not loading the lamp, can be decreased to 300V or less. Therefore, the circuit can be made small.

[0104] The controlling means 23 may comprise a microcomputer programming the above-described lamp lighting method. When the vehicle lighting apparatus using the metal halide lamp turned on, the lamp can light up at a rated luminous flux of 25% one second later, and at a rated luminous flux of 80% four seconds later, respectively. In this case, the circuit can be manufactured at a cost of 70% and at a weight of 85% compared an arrangement using AC power because of it is not necessary to include a DC-AC converter. Furthermore, since the lamp does not substantially include mercury (Hg), mercury (Hg) does not luminescent strongly at the side of anode. Therefore, a color of visible light generated by the lamp becomes even.

[0105] FIGURE 19 shows a circuit diagram of a second embodiment of an electric ballast to start a metal halide lamp. Similar reference characters designate identical or corresponding to the elements described with respect to FIGURE 18. Therefore, detail descriptions will not be provided. The circuit arrangement includes a full-bridge inverter circuit 28 made up four switching elements. A pair of switching elements 28a is connected to output terminals of a chopper circuit 22 in parallel. An oscillator 28b alternately supplies pulses to the switching elements 28a. Therefore, the lamp is supplied a high frequency alternating current.

Claims

1. A metal halide lamp comprising:

a light-transmitting discharge vessel (1) having a discharge space portion (1c), a sealed portion (1a1), a pair of electrodes (1b) projecting into the discharge space (1c);
an ionizable filling the discharge space portion (1c), which contains a rare gas and a metal halide including at least sodium (Na) or scandium (Sc) and does not substantially include mercury (Hg); and
a conductive wire (3) connected electrically to each of the electrodes (1b), the conductive wires (3) extending from the discharge vessel (1);
said metal halide lamp being **characterized in that** said metal halide lamp is constructed and arranged so as to have a D/L ratio in a range of about 0.25 to about 1.5 and a t/L ratio being in a range of about 0.16 to about 1.1, wherein L is an interspace of tips of the electrodes (1b), D is a maximum inner diameter of the discharge vessel (1), and t is a maximum wall thickness of the discharge space portion (1c).

2. A metal halide lamp according to claim 1, wherein a quantity of the ionizable filling in the discharge vessel (1) corresponds to a formula: $q \leq 71.4/t$, wherein q is a quantity (mg) per a volume of 1 (cc) of the discharge space (1c).

3. A metal halide lamp according to claim 1, wherein both an inner diameter ID (mm) and an outer diameter OD (mm) of the discharge vessel (1) and a lamp power P (W) satisfy the following formula:

$$(OD-ID) * ID / P > 0.21.$$

4. A metal halide lamp according to claim 1, wherein a pressure A (atm) at 25 degrees centigrade of xenon (Xe) and the interspace L (mm) are related according to the following formula: $1.04 \leq A/L \leq 4$; and
the ionizable filling further comprises a secondary metal halide not easily emitting visible light in comparison with the metal halide during lamp operation.

5. A metal halide lamp according to claim 1, wherein the interspace L (mm) is about 6mm or less; and
the ionizable filling further comprises one or more substance selected a group of rare earth elements.

6. A metal halide lamp apparatus comprising:

a metal halide lamp comprising a light-transmitting discharge vessel (1) having a discharge space portion (1c), a sealed portion (1a1), a pair of electrodes (1b) projecting into the discharge space (1c); an ionizable filling in the discharge space portion (1c), which contains xenon (Xe) gas and a metal halide including at least sodium (Na) or scandium (Sc) and does not substantially include mercury (Hg); and a conductive wire (3) connected electrically to each of the electrodes (1b), the conductive wires (3) extending from the discharge vessel (1); and a ballast;

said metal halide lamp apparatus being **characterized in that** said metal halide lamp is constructed and arranged so that it has a D/L ratio in a range of about 0.25 to about 1.5 and a t/L ratio being in a range of about 0.16 to about 1.1, wherein L is an interspace of tips of the electrodes (1b), D is a maximum inner diameter of the discharge vessel (1), and t is a maximum wall thickness of the discharge space portion (1c); and

said ballast is constructed and arranged so as to have a relation between a filling pressure X (atm) of the xenon (Xe) and a maximum electrical power AA (W) provided to a following formula: $3 < X < 15$, $AA \geq -2.5X + 102.5$, wherein the maximum electrical power AA (W) is a maximum wattage supplied to the metal halide lamp in four seconds after the lamp turned on.

7. A metal halide lamp apparatus according to claim 6, wherein the ballast supplies a direct current to the metal halide lamp.

8. A metal halide lamp apparatus according to claim 6, wherein the ballast further comprises:

a lamp voltage detecting means (25) for detecting a lamp voltage of about 60V or less; and

a controlling means (23) for maintaining a lamp electric power according to a detected signal generated by the lamp voltage detecting means (25).

9. A metal halide lamp apparatus according to claim 6, wherein the ballast has an output voltage of about 300V or less when the ballast does not load the metal halide lamp.

10. A vehicle lighting apparatus comprising:

a reflector (11) having an opening and accommodating a metal halide lamp; wherein the metal halide lamp comprises a light-transmitting discharge vessel (1) having a discharge space portion (1c), a sealed portion (1a1), a pair of electrodes (1b) projecting into the discharge space (1c); an ionizable filling in the discharge space (1c), which contains xenon (Xe) gas and a metal halide including at least sodium (Na) or scandium (Sc) and does not substantially include mercury (Hg); and a conductive wire (3) connected electrically to each of the electrodes (1b), the conductive wires (3) extending from the discharge vessel (1);

a front cover (12) attached to the opening of the reflector (11); and

a ballast;

said vehicle lighting apparatus being **characterized in that** said metal halide lamp is constructed and arranged such that a D/L ratio is in a range of about 0.25 to about 1.5 and a t/L ratio being in a range of about 0.16 to about 1.1, wherein L is an interspace of tips of the electrodes (1b), D is a maximum inner diameter of the discharge vessel (1), and t is a maximum wall thickness of the discharge space portion (1c); and

said ballast is constructed and arranged to have a relation between a filling pressure X (atm) of the xenon (Xe) and a maximum electrical power AA (W) that is in accordance with the following formula: $3 < X < 15$, $AA \geq -2.5X + 102.5$,wherein the maximum electrical power AA (W) is a maximum wattage supplied to the metal halide lamp in four seconds after the lamp turned on.

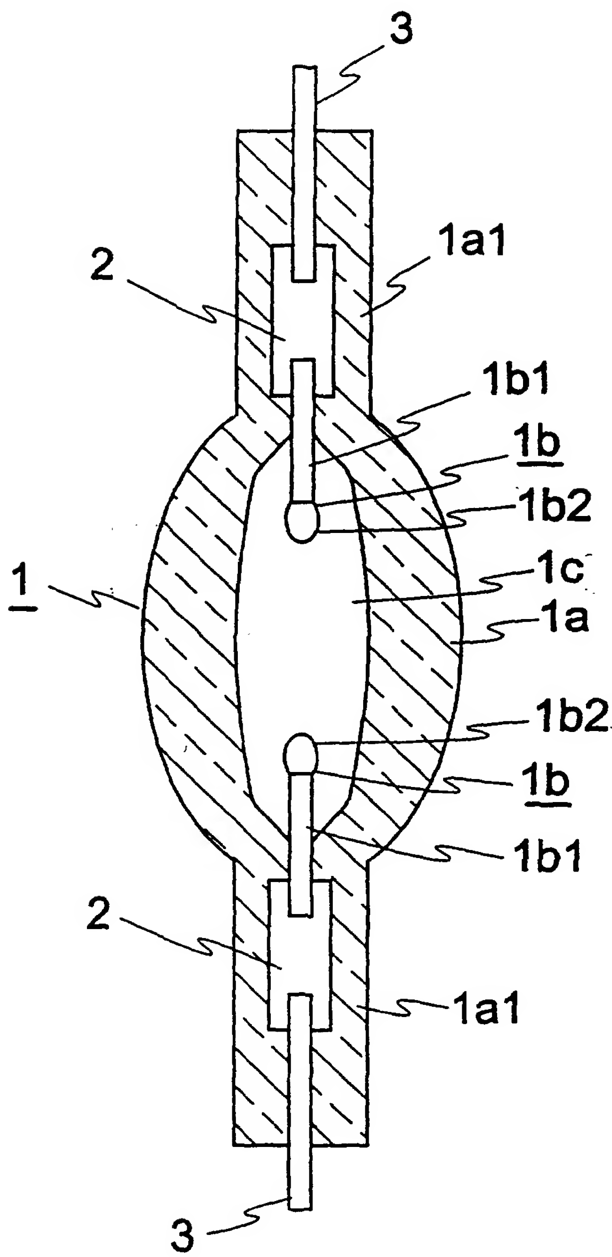

Fig.1

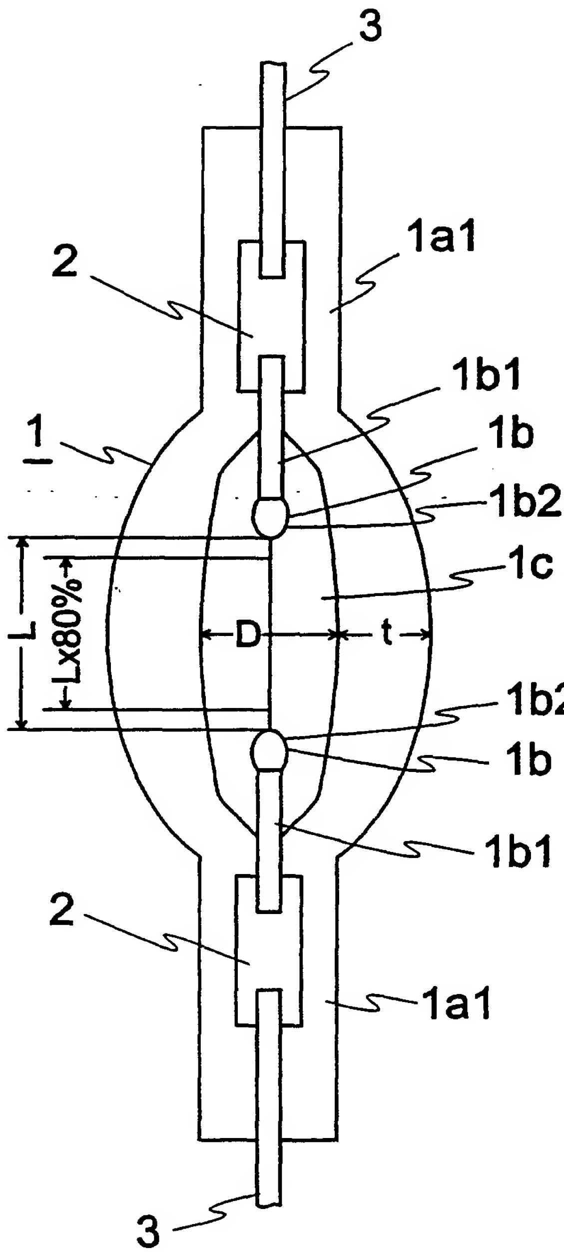

Fig.2

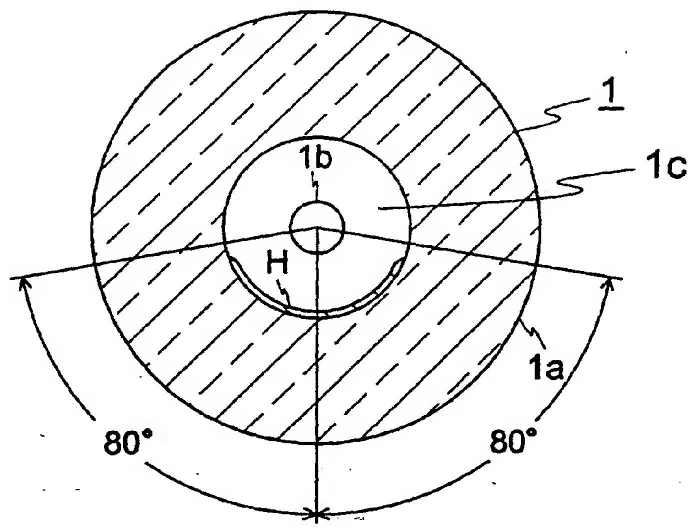
1
1c
1b
H
1a
80°
80°

Fig.3

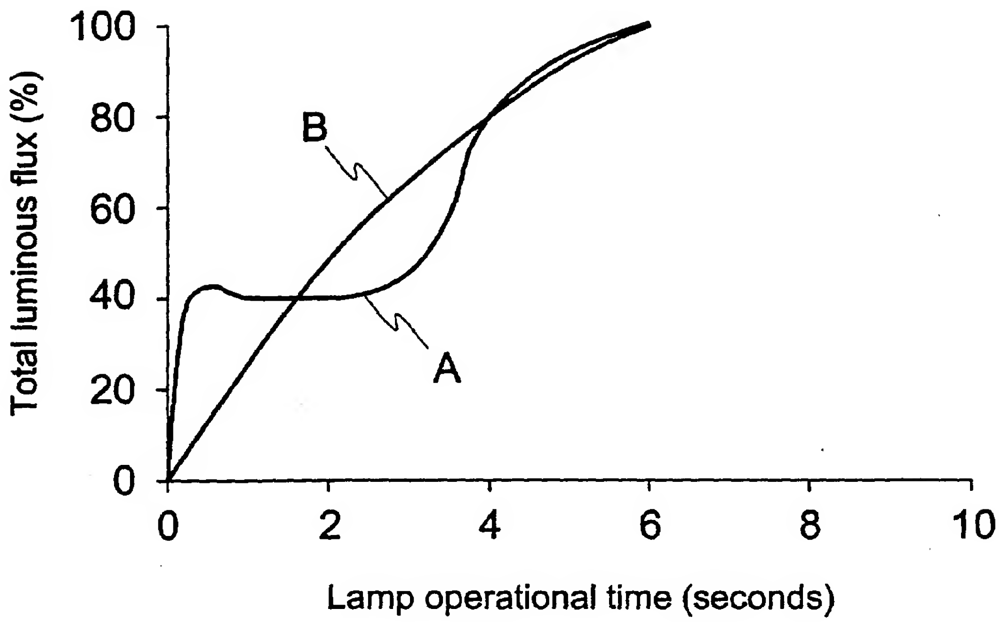
Total luminous flux (%)
100
80
60
40
20
0
0
2
4
6
8
10
B
A
Lamp operational time (seconds)

Fig.4

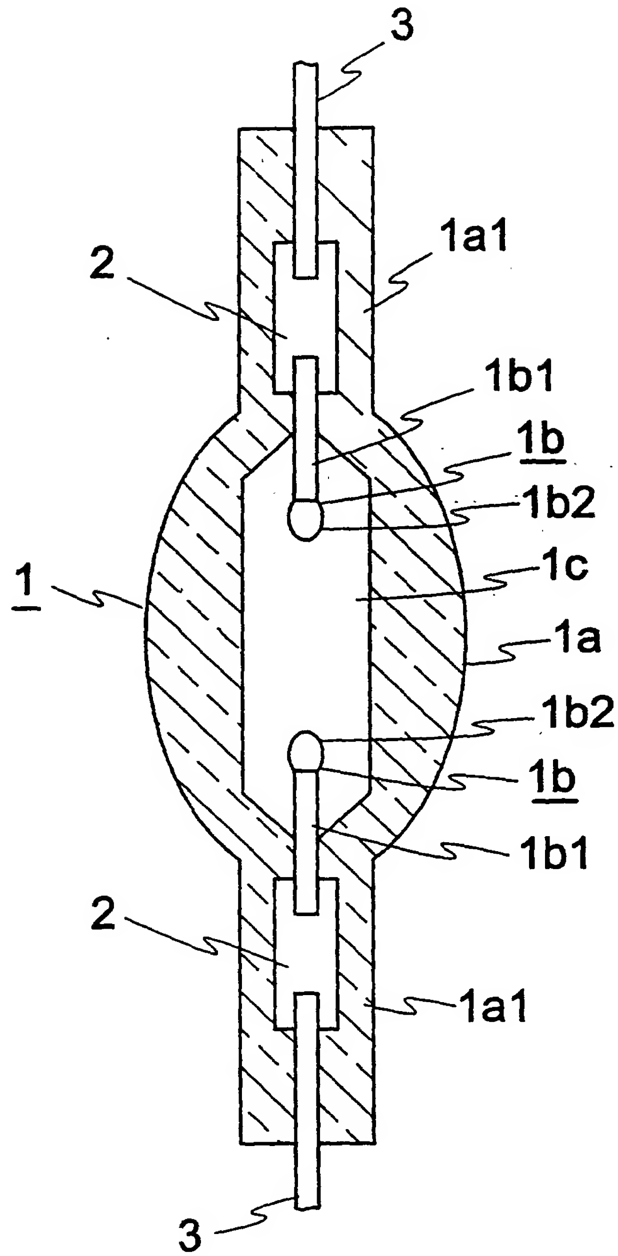

Fig.5

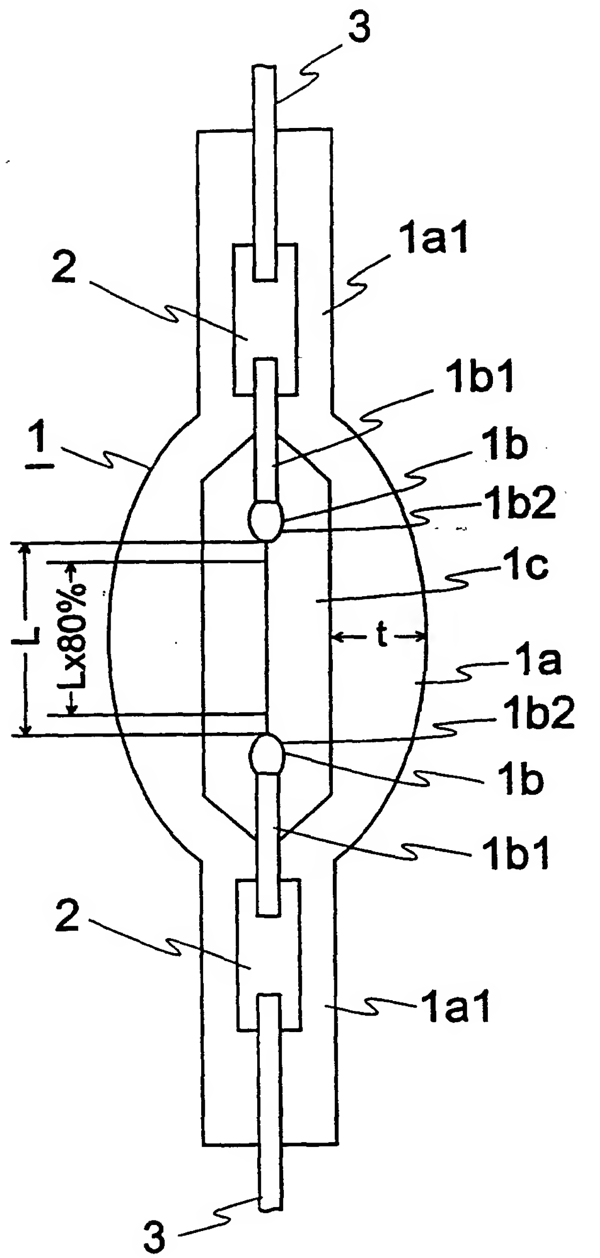

Fig.6

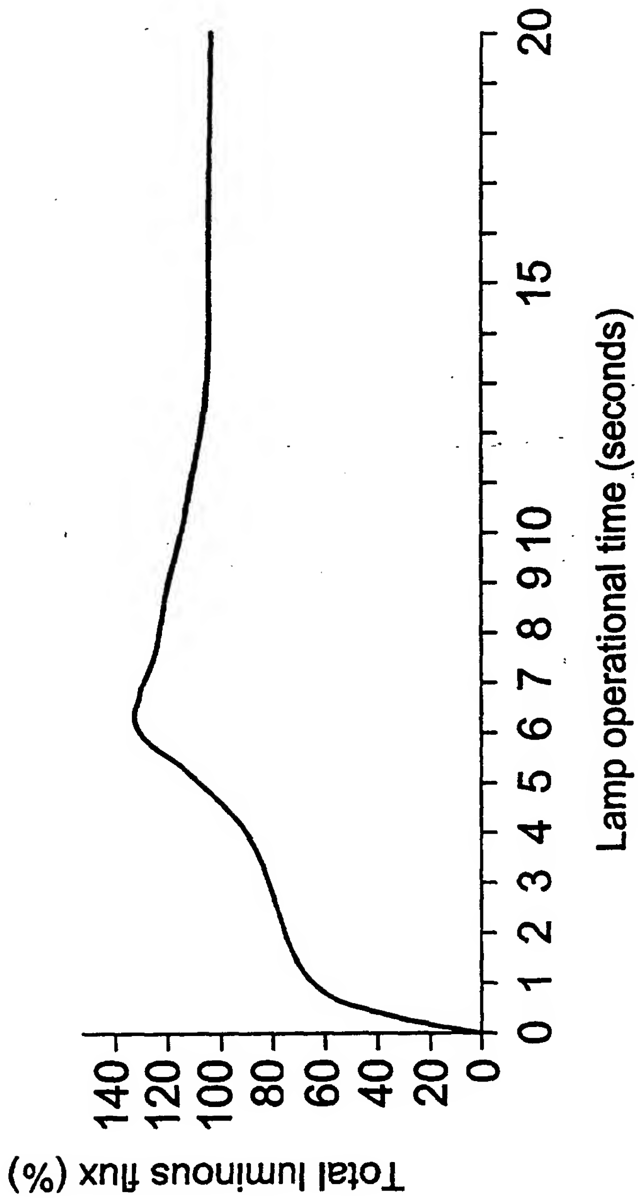
Total luminous flux (%)
0
20
40
60
80
100
120
140
0 1 2 3 4 5 6 7 8 9 10
15
20
Lamp operational time (seconds)

Fig.7

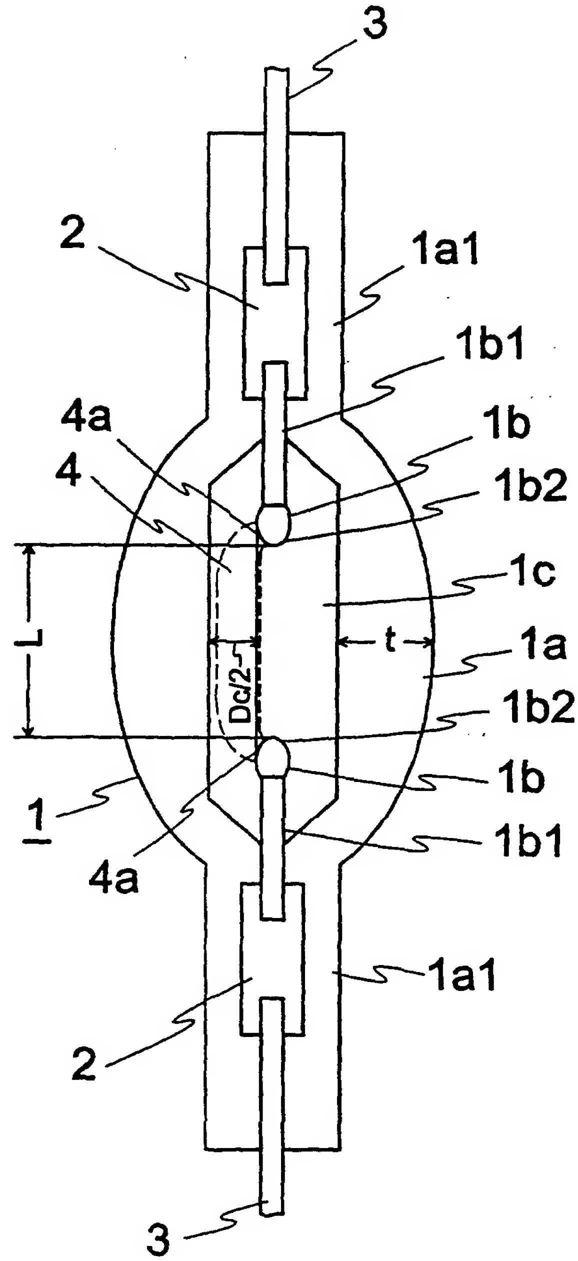

Fig.8

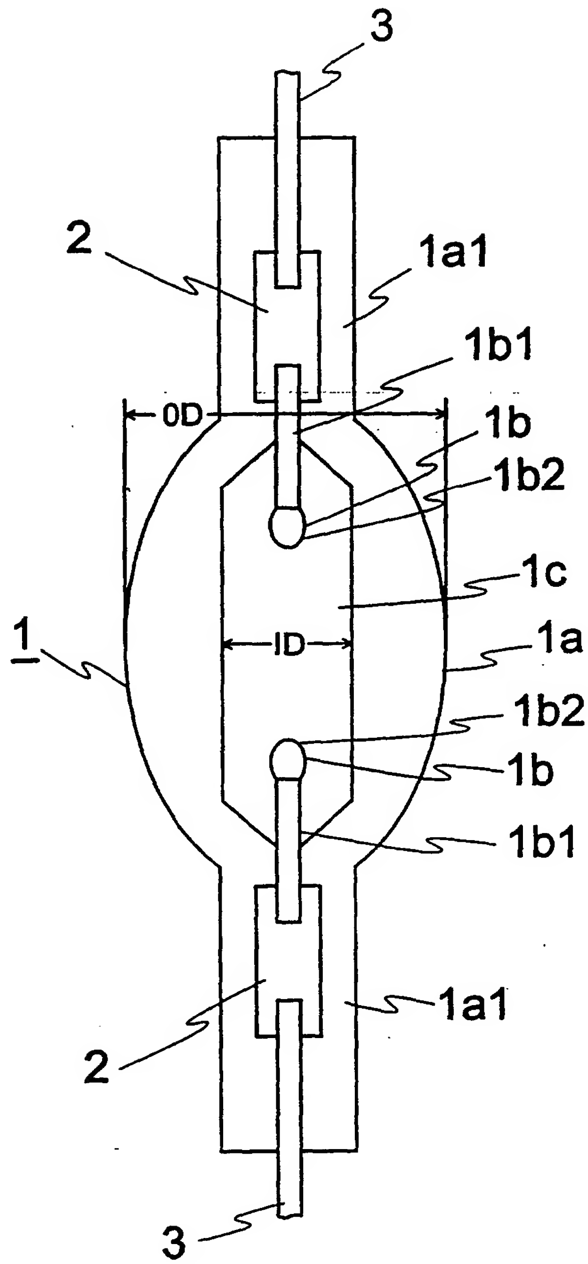

Fig.9

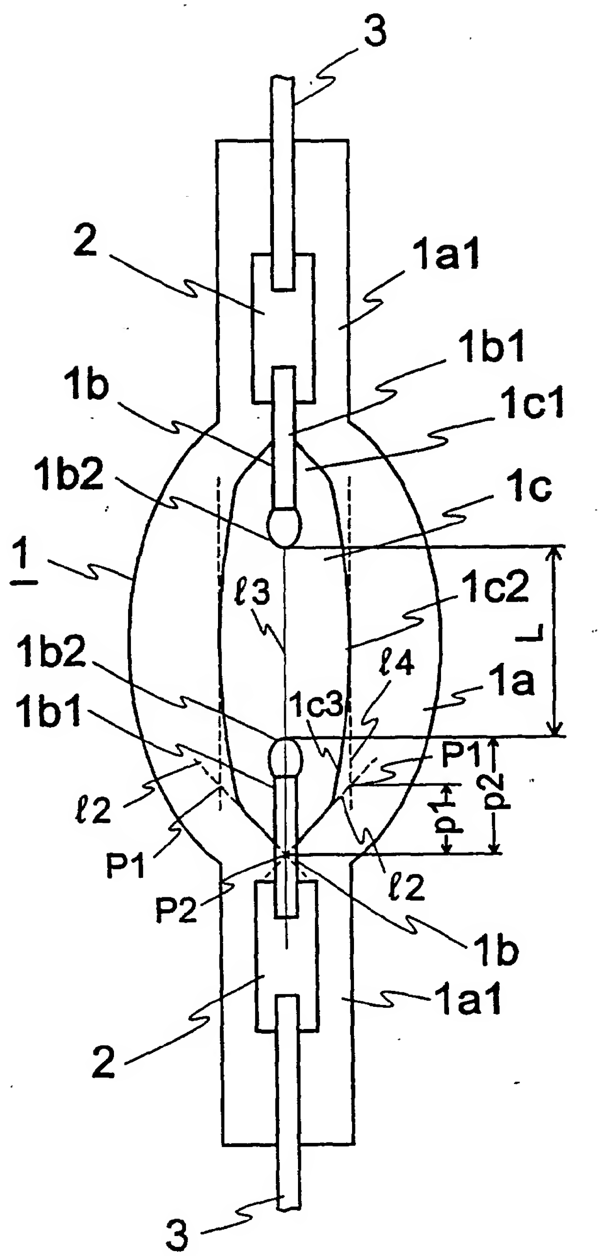
3
2
1a1
1b1
1b
1c1
1b2
1c
1
ℓ3
1c2
L
1b2
ℓ4
1a
1b1
1c3
P1
ℓ2
p1
p2
P1
ℓ2
P2
1b
1a1
2
3

Fig.10

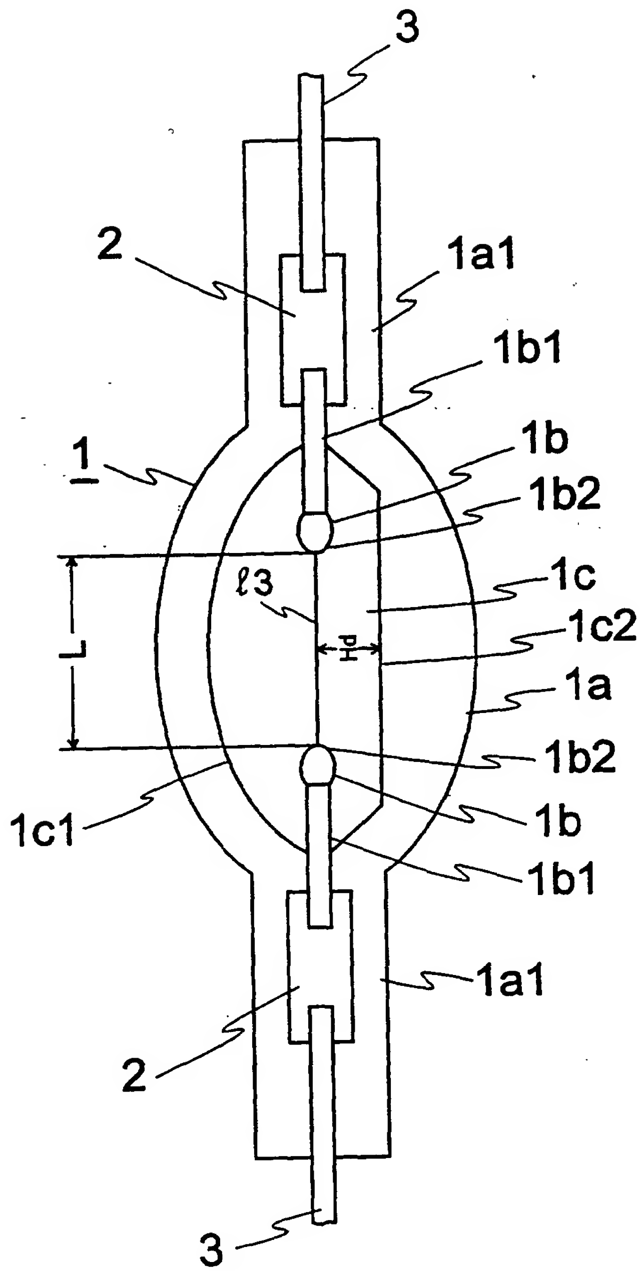

Fig.11

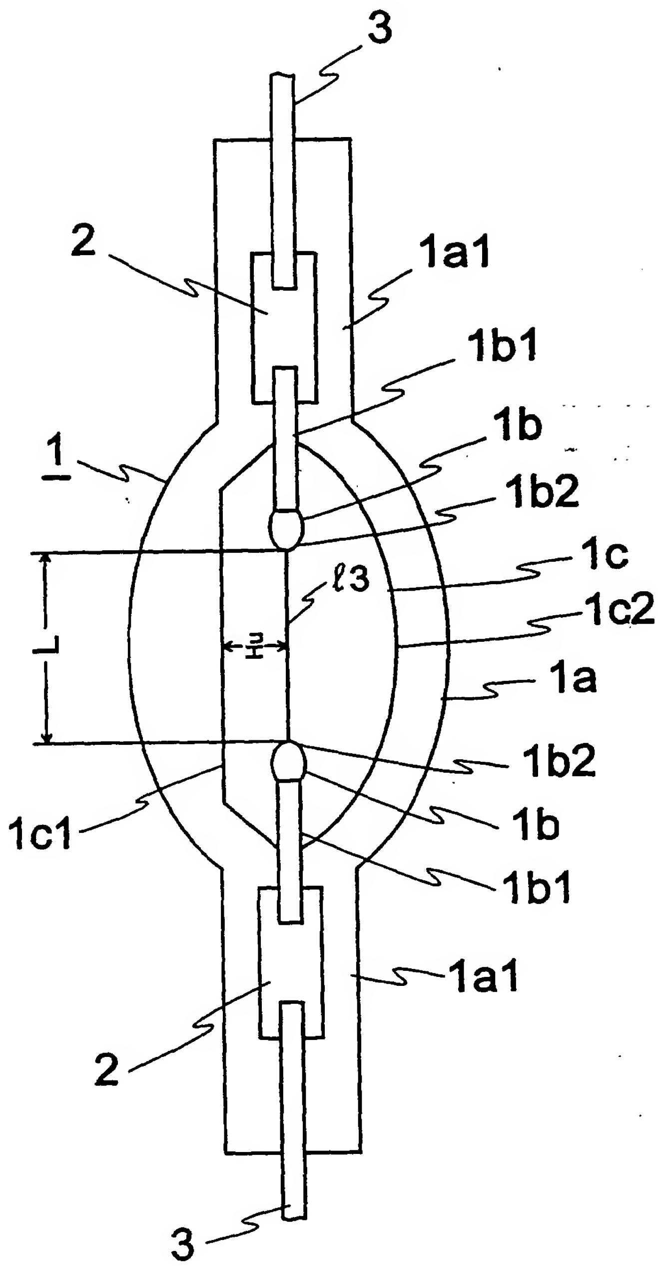

Fig.12

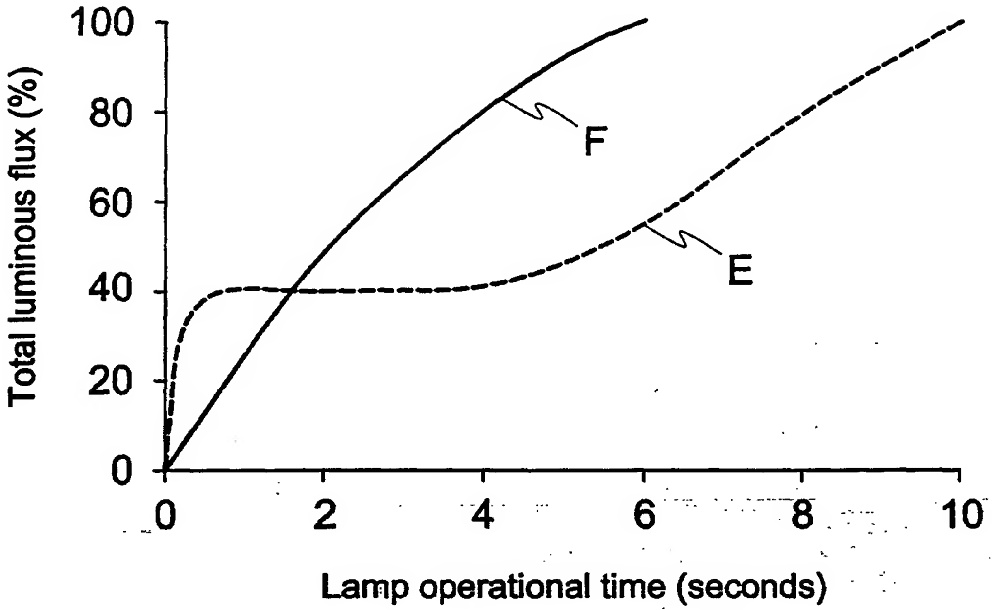
Total luminous flux (%)
100
80
60
40
20
0
0
2
4
6
8
10
Lamp operational time (seconds)
F
E

Fig.13

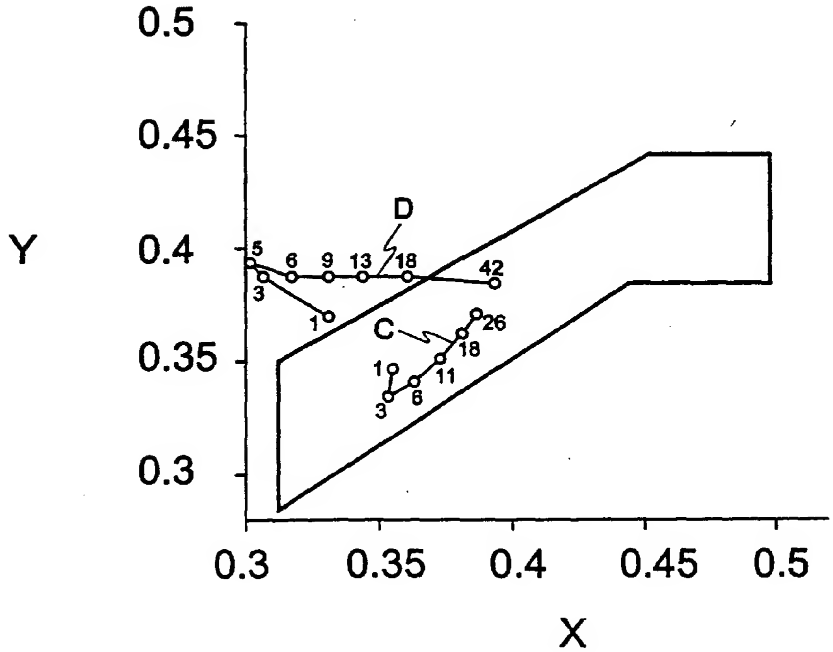
Y
0.5
0.45
0.4
0.35
0.3
0.3
0.35
0.4
0.45
0.5
X
D
5
6
9
13
18
42
3
1
C
26
18
11
1
3
6

Fig.14

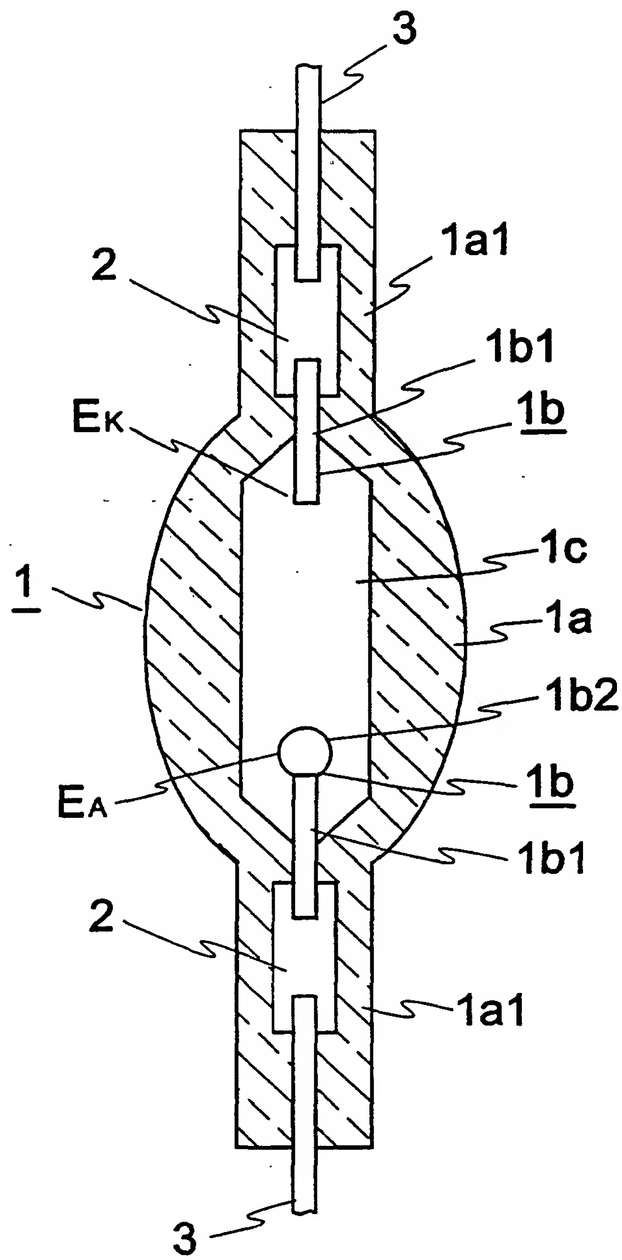

Fig.15

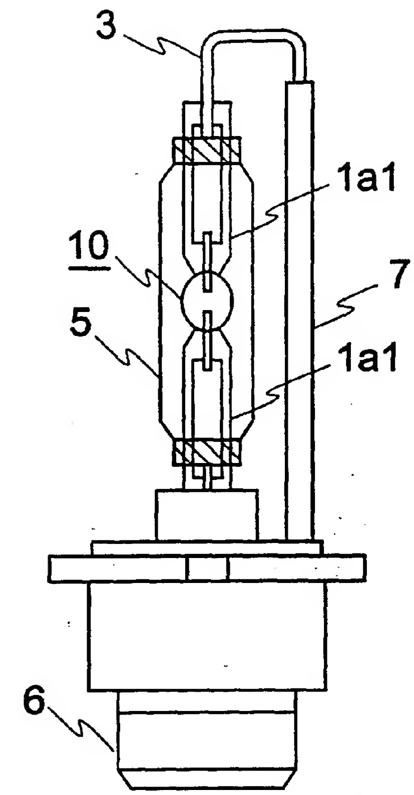

Fig.16

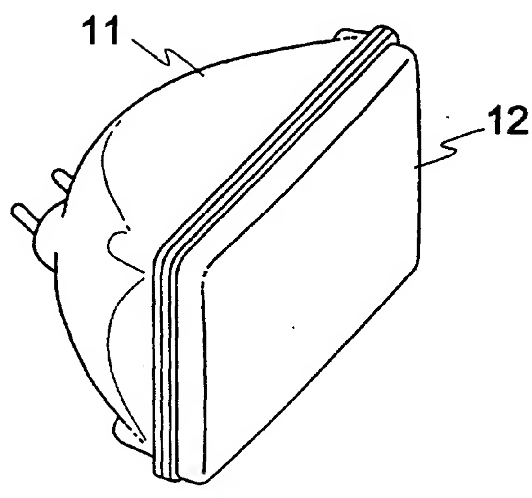

Fig.17

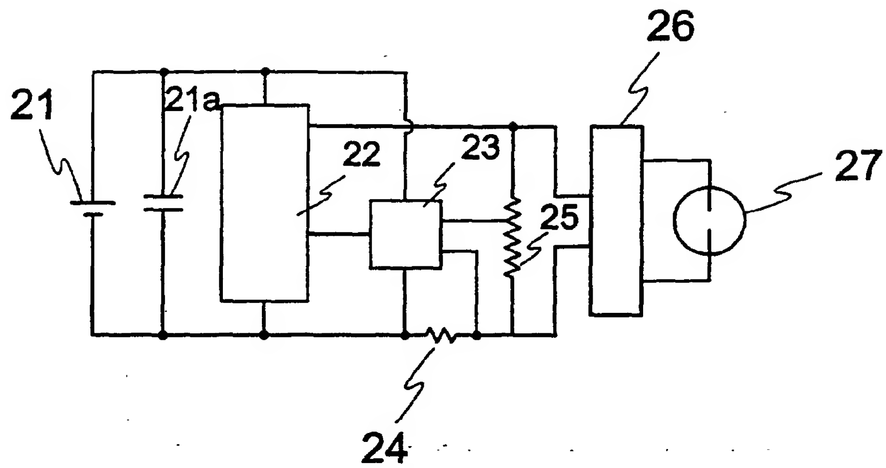

Fig.18

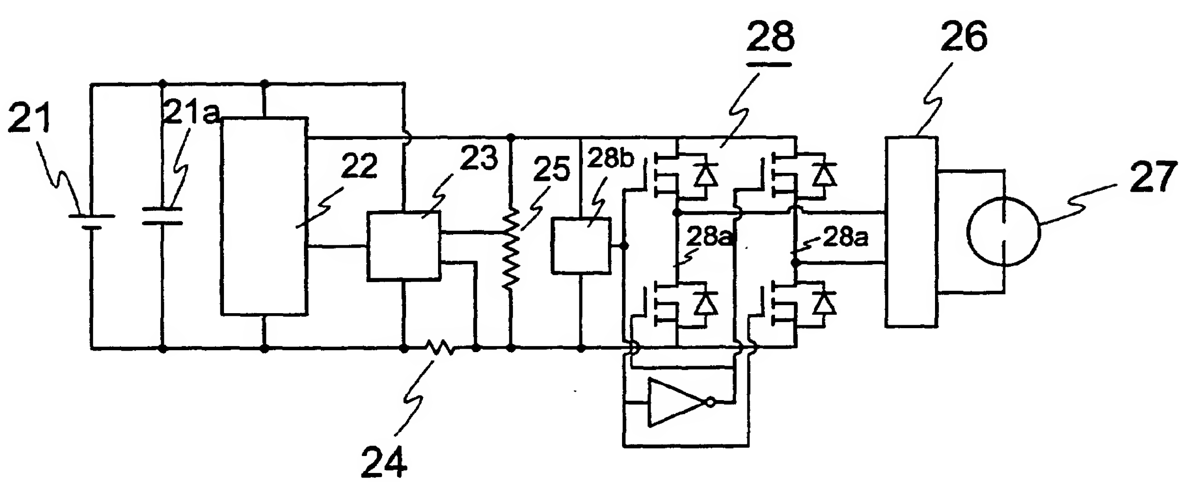

Fig.19

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 11 0353

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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X	US 5 828 185 A (HENDRICX JOSEPHUS C M ET AL) 27 October 1998 (1998-10-27) * column 6, line 42 - line 67; figure 2 *	1	
P,X	EP 1 063 681 A (STANLEY ELECTRIC CO LTD) 27 December 2000 (2000-12-27) * page 4, line 10 - line 35 * * page 8, line 6 - line 10 * * page 9, line 50 - line 56 * * page 6, line 39 - line 42 * * table 1 *	1,2,4,5	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	30 August 2001	Zuccatti, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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